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Optical Properties as Tracers of Water Mass Structure and Circulation Patterns in the Japan (East) Sea

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LONG-TERM GOALS

Our goals are to collect detailed optical and biogeochemical data sets in the global oceans to contribute to optical model parameterizations, algorithms for advanced ocean color satellite applications, and exploitation of satellite information to better understand biological-physical coupling in the oceans. In this project, we focus on the Japan/East Sea to improve our understanding of optical properties in the region, and apply this understanding to the study of circulation using optical remote sensing as a tracer of water masses.

OBJECTIVES

For the Japan (East) Sea DRI, our objectives are to coordinate research between US scientists at Scripps Institution of Oceanography, and scientists in Japan and Korea to characterize the detailed optical properties of different water masses in the JES, and to specify the variability in the properties and their potential use as water mass tracers using *in situ* optics and remote sensing. Our overall hypothesis is that the JES can be defined in terms of 5 optical provinces with characteristic inherent and apparent optical properties (IOPs and AOPs) related to optically important seawater constituents. The 5 optical provinces include the Kuroshio Current intrusion through the Tsushima Strait, the East Korea Warm Current which entrains water from the Yellow Sea, coastal regions of Japan south of the Tsugaru Strait, the northern, sub-polar waters of the Tsushima Basin and Japan Basin, and finally, coastal regions north of the Tsugaru Strait.

APPROACH

On 5 cruises we measured the IOPs and AOPs within the JES using both an integrated *in situ* optical profiling system, and by analyzing water samples collected during hydrocasts so that the constituent optical properties were specified. For the most comprehensive cruise on R/V Revelle, our *in situ* profiling system included spectral downwelling irradiance and upwelling spectral irradiance and radiance (Ed, Eu, Lu), diffuse attenuation (K), absorption (a), scattering (c) and backscattering (bb). For R/V Khromov and NFRDI collaborative cruises, the *in situ* optics were limited to spectral reflectance (Ed, Lu) data. *In situ* optics combined with water sample analyses will be used to develop specific parameterizations of IOPs as input to a radiative transfer model of ocean optics in the JES.

Combining data from *in situ* and laboratory measurements with radiative transfer modeling will allow us to achieve the best possible estimates of the IOPs and AOPs which are of most direct interest to water mass characterization.

Full resolution data from SeaWiFS and AVHRR has been collected and archived by our Korean colleagues at NFRDI and KORDI. We are collaborating with them on developing algorithms from the combined *in situ* database, and in analysis of the data for studies of circulation. Using the large data sets that have been acquired we will develop algorithms for retrieval of IOPs and other standard variables from ocean color imagery and validate our models. Finally, we will apply these algorithms to the OCTS, SeaWiFS and MODIS ocean color time series to study water masses and circulation of the JES.

WORK COMPLETED

We have carried out a satellite study of a cold-core quasi-stationary eddy located off the coast of North Korea (Suh et al., 1999). In June 1999 we participated in the hydrographic survey cruise of the R/V Revelle in the Korean and Japanese waters of the JES. Following this cruise, we transferred some of our equipment onto the R/V Khromov and Dr. Sergei Zakharkov of the Pacific Oceanological Institute in Vladivostok carried out a mimimal set of observations in Russian waters for absorption, ocean reflectance using SIMBAD, and pigments. Young Sang Suh from the Korean National Fisheries Research Development Institute (NFRDI) initiated cruises to waters southwest of Korea corresponding to source waters flowing through the Tsushima strait. Three NFRDI cruises have been completed in 2000 and we participated on the first two to train NFRDI scientists. We coordinated a regional ocean color algorithm symposium and planning meeting 17-19 September 2000 at NFRDI in Pusan, Korea. At the planning meeting participants from Korea, Japan, China, Taiwan, Hong Kong and the US agreed to merge data and embark on a collaborative effort for regional optical algorithm development. Data will be merged and analyzed and a detailed algorithm workshop is planned for June 2001.

RESULTS

The Japan (East) Sea (JES) is a marginal sea with a complex hydrographic structure that is clearly evident in satellite sea surface chlorophyll imagery (Figure 1a). Our work is concerned with applying optical observations from satellites and K-SOLO to better understand the details of circulation and water mass dynamics of the surface waters (0-300m). Results from K-SOLO are presented in a separate annual report. The location of stations for our most detailed optical survey within the JES on R/V Revelle in June-July, 1999 are shown in Figure 1b overlaid on satellite chlorophyll imagery. To properly understand the role of transport of waters of different optical characteristics into the JES through the Tsushima Strait requires an understanding of the optical properties of the source waters. Based on two cruises in collaboration with the Korean NFRDI southwest of the Tsushima Strait, we found that the East China Sea west of Cheju Island can have very heavy suspended sediment loads and elevated concentrations of absorption due to soluble material (cDOM) compared to the Kuroshio waters. The flow entering the Tsushima strait typically branches; one branch follows the Korean coast, the other follows the Japanese coast. Thus, the East Korea Warm Current contains a significant volume of water from the East China Seas and may carry sediments or soluble material from that region. We hypothesize that semi-analytical models applied to ocean color data will allow us to track coastal branches on the east and western sides of the JES based on the optical component (e.g. cDOM, backscattering, and particle absorption) characteristics to complement more traditional means of water mass characterization.

We have found that SeaWiFS still has problems with accurate retrievals in channels 1 and 2 (412 and 443 nm) (Kahru and Mitchell, 1998; 2000). As shown by Kahru and Mitchell (2000) the semi-analytical algorithm of Carder et al., (1999) significantly over-predicts cDOM and under predicts chlorophyll when applied to SeaWiFS data in the California Current because of these systematic underestimates of Lwn at 412 and 443 nm. Using our detailed East Asian data sets we will validate

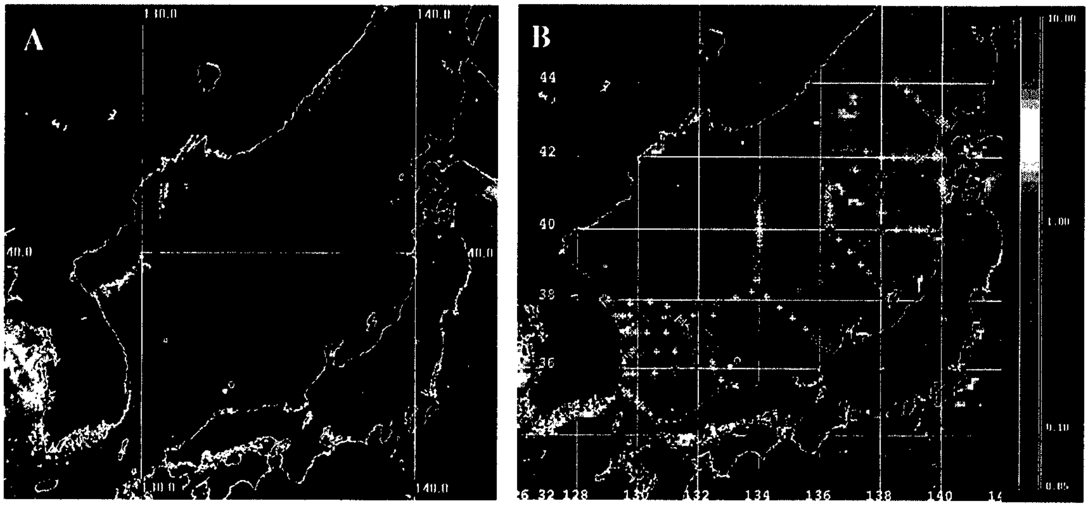

Figure 1A. High resolution (HRPT) SeaWiFS chlorophyll image of the Japan (East) Sea and waters west of the Tsuchima Strait from March 2000. The surface location of the K-SOLO temperature drift profiler during the period March–August 2000 is indicated by the red track. The image clearly shows the low pigment Kuroshio waters entering the JES southeast of Cheju Island, and the continuity of high turbidity water from the East China Sea following the southern coastline of Korea. B. The station locations of the R/V Revelle June-July 1999 survey in the JES overlaid on the June monthly composite image of SeaWiFS chlorophyll; station with red symbols correspond to optical profile stations.

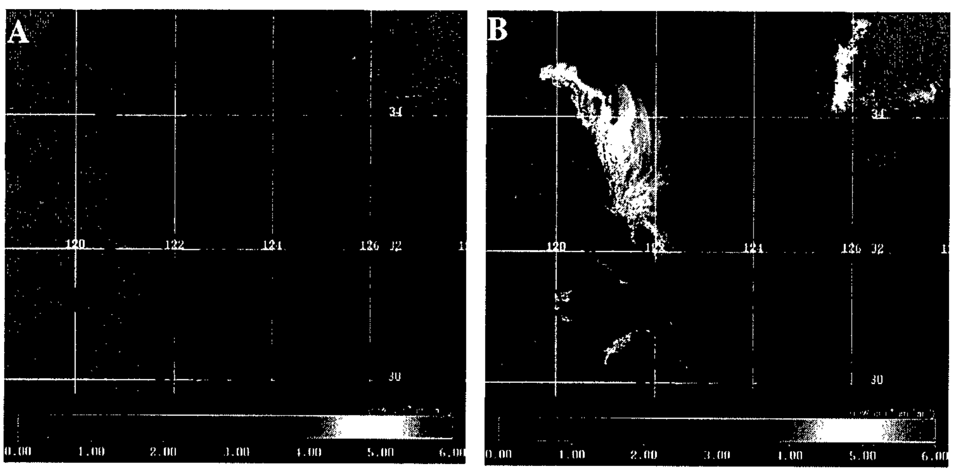

Figure 2. Water leaving radiance (Lwn) at 510 nm for a high resolution (HRPT) SeaWiFS scene for the East China Sea region. The left panel (A) is the result using the standard NASA algorithm available in SeaDAS v4.0 (released May, 2000). SeaDAS v4 produces negative Lwn(510) values near the coast of China and unrealistically low values in the main plume of the Yangtze River. The right panel (B) is the result using the procedure of Ruddick et al., (2000) which produces physically realistic values of Lwn(510) and realistic gradients within the Yangtze River plume. Useful application of SeaWiFS or other ocean color satellite data for this region will require continued research and more advanced algorithms, as well as validation of retrievals with in situ data.

SeaWiFS retrievals and make modifications to the processing codes within SeaDAS as required to achieve accurate water leaving radiances that can be used in inversion models. Figure 2a shows that the new standard NASA processing algorithm that uses a chlorophyll-dependent spectral backscattering term to estimate near IR reflectance (Siegel et al., 2000) still cannot retrieve accurate reflectance in turbid case 2 waters of the East China Sea and the plume of the Yangtze River. We have implemented an alternative atmospheric correction (Ruddick et al., 2000) that provides realistic retrievals for the same scene (Figure 2b). In collaboration with our Korean colleagues at NFRDI and KORDI, we will validate these alternative corrections, and if necessary modify them so that accurate spectral water leaving radiances can be achieved. Thus, one of our tasks will be to identify and characterize the specific optical signatures associated with these suspended particulates of terrigenous origin. The routine cruises as part of the Korean National Fisheries Research Agency will provide data on spectral reflectance, particle and soluble absorption, as well as pigments, particulate organic carbon and suspended particle mass.

In specifying the optical signatures of water masses in the JES we plan to explore two important features of the variability in the near surface particulate assemblages and associated optics as we advance from coastal to offshore provinces or water masses. First, we expect that a seaward decrease in the content of terrigenous silt-sized particles (due to sinking) will be accompanied by a relative increase in clay-sized particles, which are too small to sink rapidly. This hypothesis will be examined through microscopic analyses of mineral samples collected during the June-July R/V Revelle cruise. Any changes in the size distribution of particles should be reflected in the IOPs, especially scattering properties of seawater, and therefore they should serve as possible tracers of associated water masses. Second, we expect significant changes in the particle composition, and hence refractive index distribution, such that particles suspended in the offshore surface waters will be typically dominated by a relatively greater fraction of biological material with low refractive index. This type of material may also dominate optics in some coastal areas, especially in the spring and/or summer (e.g. coastal red tides). The non-biological material composed of mineral grains with high refractive index will be typically most important in coastal surface waters and/or near-bottom waters. Compositional differences will cause variations in the absorption and scattering properties of seawater, which may then provide characteristic optical signatures of associated water masses.

Organic detritus or minerals in suspended sediments of case 2 waters off southwest Korea create large differentiation in chlorophyll normalized particulate absorption spectra compared to the case 1 waters observed during the R/V Revelle cruise in the JES (data not shown). The strong influence of suspended detrital pigments will preclude general application of global parameterizations of chlorophyll specific absorption coefficients that are available. Absorption by soluble material (a_s) can exceed absorption by particulate matter (Mitchell et al., 1996) and therefore must be considered. We anticipate that different water masses in the JES will likely have different magnitudes of $a_s(\lambda)$ and also different spectral shapes due to varying proportions of the constituent components. We made detailed measurements of the absorption components on our various cruises and these data sets will be the basis for our model development. The scattering properties [$b(\lambda)$, $b_b(\lambda)$] may assist in characterizing water masses as they depend on the concentration and composition of particulate matter. The scattering and the beam attenuation coefficients associated with a broad size range of particles are also expected to provide useful optical signatures, for example for tracing coastal water masses characterized by input of terrigenous particles (river discharge, land runoff) or tracing water masses transported from East China Sea with characteristic particulate assemblages. For the R/V Revelle survey, we accomplished detailed vertical profiles with AC9 and Hydroscat 6 of spectral absorption, attenuation and backscatter. On all projects we measured spectral absorption coefficients and reflectance. The combined data sets will be integrated with data collected by our regional colleagues to develop forward model parameterizations and advanced inverse models to retrieve IOPs from spectral reflectance.

IMPACT/APPLICATIONS

During the next year we will integrate our comprehensive data to regional data sets collected by Japanese, Korean, Chinese and Russian colleagues to develop a comprehensive understanding of the optical properties of the JES and source waters of the Kuroshio and East China Sea. Merged data will serve as the source data for advanced optical model parameterization. Optical modeling and algorithm development will allow advanced applications of ocean color data for the retrieval of IOP and regional attenuation coefficients. The algorithms will be applied to ocean color satellite imagery to improve understanding of surface water circulation in the region.

TRANSITIONS

We have published an article using drifters and satellites to describe a quasi-stationary eddy off the North Korean coast (Suh et al., 1999).

RELATED PROJECTS

This project is one of numerous projects funded under the ONR DRI Japan East Sea program. We plan to coordinate our optical and hydrographic analyses with other investigators.

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